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955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

SUBJECT: Use of State Vectors to Identify the CSM and S-IVB in Photographs of the Apollo 8 Mission - Case 340

DATE: March 7, 1969

FROM: W. D. Grobman

ABSTRACT

State vectors obtained from S-band tracking and from the IU are used to confirm the previous identification of the CSM and S-IVB in Smithsonian Photographs of the Apollo 8 mission. This is probably the first time that photographs of objects on a trans-lunar trajectory have been used to test the accuracy of state vectors obtained from radar tracking and inertial guidance telemetry.

(NASA-CR-106705) USE OF STATE VECTORS TO IDENTIFY THE CSM AND S-4B IN PHOTOGRAPHS OF THE APOLLO 8 MISSION (Bellcomm, Inc.) 8 p

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MEMORANDUM FOR FILE

Recently there has been interest in photographs of the Apollo 8 mission taken when the spacecraft was about 40,000 km from the earth (see, for example, Buffalano, Grobman 1969). Figure 1 shows one such photograph, taken from San Fernando, Spain by a Baker-Nunn satellite tracking camera. This camera is part of a network operated by the Smithsonian Astrophysical Observatory and is an f/1, 20" aperture Schmitt-Casegrain telescope with a field of view of about 5°. The objects in Figure 1 have been identified previously (Buffalano, Grobman 1969) on the basis of arguments depending on the nominal post trans-lunar-injection mission sequence for Apollo 8. In particular, Object 2 was identified as the S-IVB and Object 3 as the CSM.

In the present memorandum we confirm this identification using state vectors obtained from GSFC and MSFC.* This is done by determining where objects at the positions given by the S-IVB and CSM state vectors would appear against the stellar background as seen by an observer at San Fernando, Spain. These positions predicted on the basis of the state vectors can then be compared with the positions of the objects seen in the Baker-Nunn photographs.

This procedure was followed for a particular Smithsonian photograph -- one taken at 18:21:11 universal time (about 5-1/2 hours after launch). A brief summary of the procedure followed is given in the Appendix, which also contains a discussion of the sources of error in the results.

The Smithsonian Observatory has measured the positions of Objects 2 and 3 in their picture taken at 18:21:11 universal time. In January 1, 1969 celestial coordinates these positions are:

Object 2:	Right Ascension	305.9720°
	Declination	1.8661°
Object 3:	Right Ascension	306.0155°
	Declination	1.8172°

*The CSM state vector was obtained from S-band range and range rate data, while the S-IVB state vector came from the inertial guidance system on the S-IVB.

Using state vectors obtained from GSFC and MSFC (see Acknowledgements), the predicted positions of the S-IVB and CSM as seen from San Fernando, Spain (using the procedure sketched in the Appendix) were:

S-IVB:	Right Ascension	305.9622°
	Declination	1.8542°
CSM:	Right Ascension	306.0117°
	Declination	1.8220°

These results are shown graphically in Figure 2, which confirms the identification of Object 2 as the S-IVB and Object 3 as the CSM. The difference between the state vector and photographic positions of the objects (∿ 7 km) is small compared to the distance between the CSM and S-IVB (∿ 50 km).

This confirmation of the previous identification is important because it helps show that the large amount of scattered light near Object 2 is not relevant to the problem of star sightings from a manned spacecraft since the scattering cloud does not accompany the CSM. An important implication of the availability of the technique described here is that, in conjunction with the complete series of photographs taken by the Smithsonian, it might be used to check whether there are any large systematic errors in S-band state vectors. Whether this use of these photographs is worthwhile needs further study.

ACKNOWLEDGEMENTS:

The author would like to thank D. McFadden of MSFC and G. Barsky of GSFC for supplying S-IVB and CSM state vectors. Also, M. Kelley of Bellcomm (Department 2014) generated state vectors for the time the picture was taken from the MSFC and GSFC state vectors.

W. D. Grobman

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Attachments
Appendix
Reference
Figures 1 & 2

APPENDIX

Outline of the Procedure for Obtaining Celestial Coordinates of S-IVB and CSM from State Vectors and from the Smithsonian Photographs

A. Method of Obtaining Celestial Coordinates of Objects 2 and 3 from Smithsonian Photographs taken at San Fernando, Spain:

1. 1950 celestial coordinates of Objects 2 and 3 were generated by the Smithsonian by measuring positions of the objects with respect to stars in the known background starfield.

2. Right Ascension and Declination were corrected to a 1969 coordinate system. (The celestial coordinate system is based on the orientation of the earth and drifts across the sky as the earth precesses, nutates, etc.)

B. State Vector-based Celestial Coordinates of the CSM as Seen from San Fernando, Spain:

1. The position vector of the CSM was obtained in a 1969 coordinate system by using the position part of the state vector (the complete state vector also gives velocity). This vector is denoted $\underset{\sim}{R}$.

2. The position vector $\underset{\sim}{r}$ of San Fernando, Spain at 18:21:11 universal time on 12/21/68 was found. This was done as follows:

   a. Length of vector = 1 earth radius.

   b. Declination of $\underset{\sim}{r}$ is just 90° - (latitude of San Fernando, Spain).

   c. Right ascension of $\underset{\sim}{r}$ is the local sidereal time at San Fernando.

3. Find the vector $\underset{\sim}{R}-\underset{\sim}{r}=\underset{\sim}{S}$. This vector points in the direction of the CSM as seen by an observer at San Fernando. ($\underset{\sim}{R}$ points in the direction of the CSM as seen by an observer at the center of the earth.)

4. The declination of the CSM as seen from San Fernando is then $90° - \cos^{-1}(S_z/|\underset{\sim}{S}|)$, while the Right Ascension is $\tan^{-1}(S_y/S_x)$.

C. A similar procedure gives the coordinates of the S-IVB based on the MSFC state vector.

There are several sources of small errors in the procedure outlined above. These errors combine to cause the differences between state vector positions and measured positions shown in Figure 2. Some of the errors that have been identified are listed below:

A. Errors in the Smithsonian Astrophysical Observatory-based coordinates

1. Errors in measuring star positions. These should be no more than a few seconds of arc and are negligible.

2. Differential refraction. This error occurs because some of the fiducial stars on the Baker-Nunn plates have been refracted by the atmosphere to a different degree than other ones. Since the coordinates of Objects 2 and 3 are measured relative to these stars, this causes an error in the measured coordinates. This error can be significant in the photograph in question.

3. Errors in transferring the 1950 coordinates obtained from the Smithsonian to 1969 coordinates. This transformation is larger than the scale of Figure 2, and thus small errors in it are significant. Indeed, I only used a first order transformation which did not account for nutation, irregularities in the earth's motion, the changing length of the day, etc.

4. Dimensional instability in the film.

B. Systematic errors in the state vectors

These are probably too small to account for the remaining discrepancies in Figure 2, as far as the CSM is concerned. The S-IVB state vector is not as accurate as the one for the CSM because it was obtained from real time telemetry from the IU rather than from S-band tracking. This can explain the poorer agreement in the case of the S-IVB compared to the CSM.

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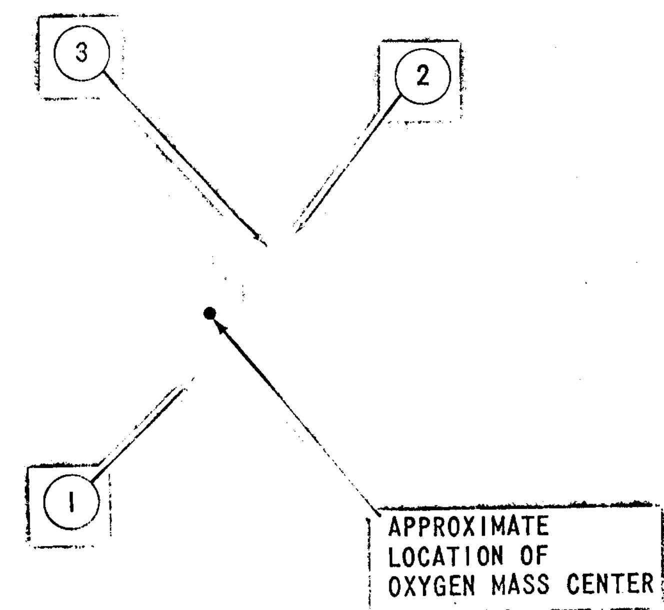
REFERENCE

A. C. Buffalano and W. D. Grobman, "Smithsonian Photographs of Apollo 8 Vented Gas Cloud," Bellcomm Memorandum for File, February 6, 1969.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OXYGEN MASS CENTER

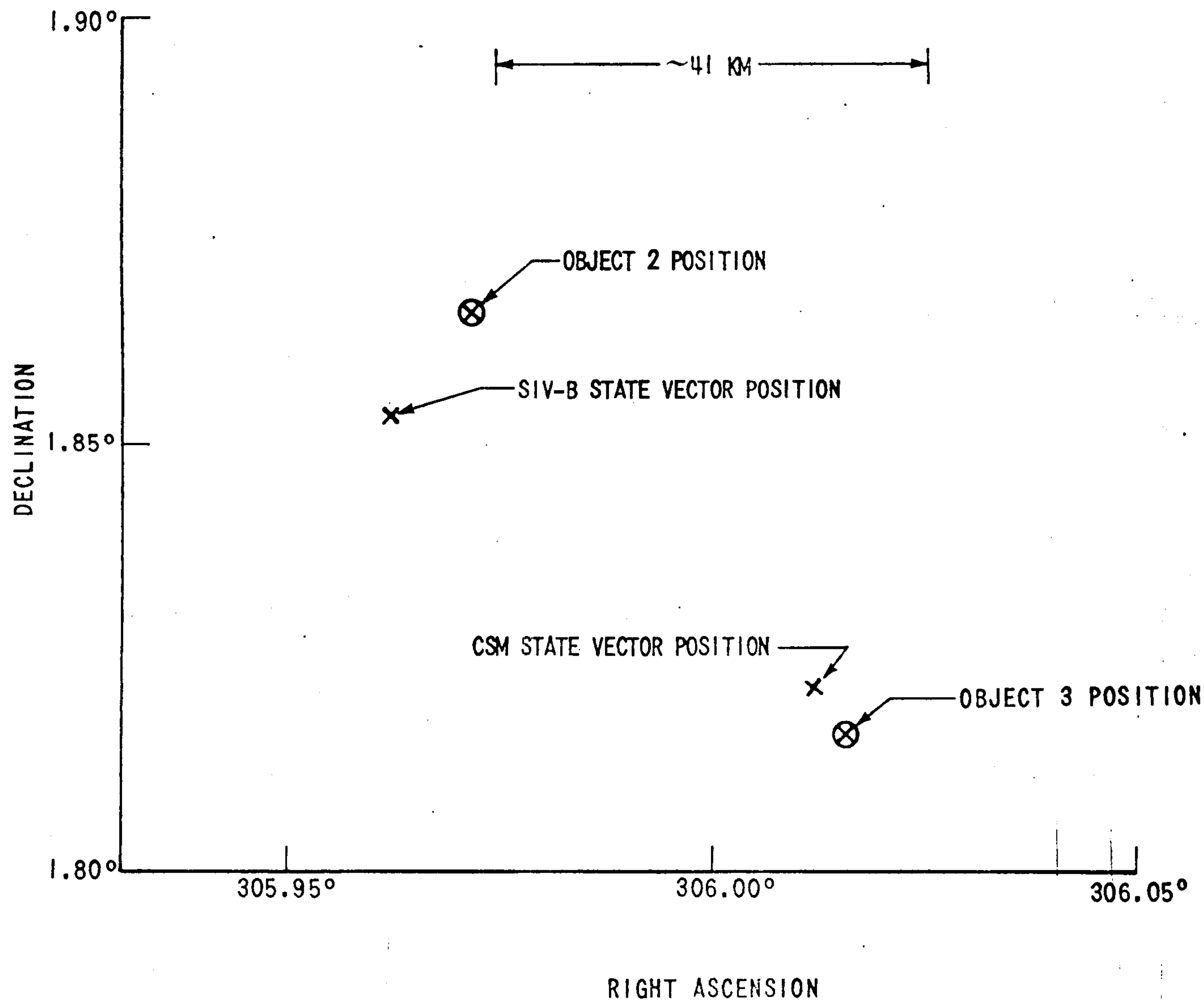

FIGURE 2 - POSITION OF SIV-B AND CSM AT 18:21:11 UT ON 12/21/69 AS SEEN FROM SAN FERNANDO, SPAIN